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The NA62 experiment for the study of kaon rare decays at the CERN Super Proton Synchrotron

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Summary. — The NA62 experiment has been designed to measure the branching fraction of the decay $K^+ \to \pi^+ \nu\overline{\nu}$ with $\sim$ 10% precision in two years of data taking at the CERN SPS. The branching fraction of this decay is calculated with a precision of few percents within the Standard Model and its measurement can put constraints on new physics scenarios complementary to LHC physics. In this paper, the NA62 experimental layout and the current status of detector construction will be presented.

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PACS 11.30.Hv – Flavor symmetries.
PACS 29.40.-n – Radiation detectors.

1. – Introduction

The $K^+ \to \pi^+ \nu\overline{\nu}$ decay is a flavour-changing neutral-current process. It is very clean from the theoretical point of view, since the hadronic matrix elements can be extracted from experimental observables, and its branching ratio (BR) can be calculated with very good precision in the standard model (SM). A recent calculation results in $\mathrm{BR}(K^+ \to \pi^+ \nu\overline{\nu}) = (0.78 \pm 0.08) \times 10^{-10}$, where the biggest uncertainties come from the CKM matrix elements [1]. This decay is highly suppressed in the SM and a precise measurement of its BR represents a very sensitive test of new physics, complementary to the one accessible in LHC experiments.

The most precise measurement of the BR has been performed by the experiments E787/E949 at BNL [2], and its value $\mathrm{BR}(K^+ \to \pi^+ \nu\overline{\nu}) = (1.73\ ^{+1.15}_{-1.05}) \times 10^{-10}$ is based on 7 events in total.

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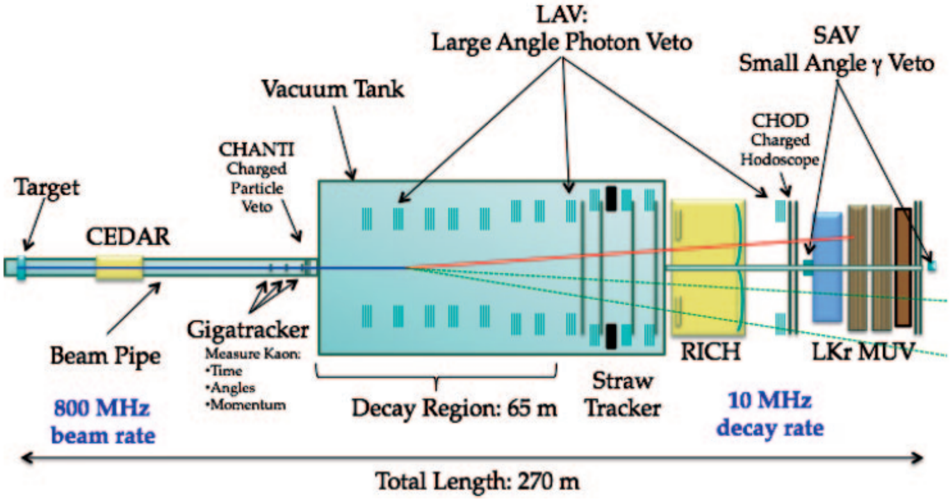

Fig. 1. – Schematic NA62 experiment layout.

To bridge the gap between the precise theoretical prediction and the relatively poor precision of the experimental result, the NA62 Collaboration decided to build a challenging detector with the aim of measuring $\mathcal{O}(100)$ events of this ultra-rare decay with $\sim 10\%$ background in two years of data taking at the CERN SPS [3, 4].

2. – Experiment layout

NA62 is a fixed target experiment at the CERN SPS, and a schematic drawing of its layout is shown in fig. 1. Primary protons from the SPS impinge on a beryllium target, and a secondary beam is selected with positively charged particles in a narrow momentum band ($75 \pm 0.7\,\mathrm{GeV}/c$).

2·1. *Principle of the experiment.* – This measurement is extremely complex from the experimental point of view because of the backgrounds due to the main K^+ decay channels and the weak signal signature (one π^+ track in the 3-bodies final state matched to one K^+ track in the beam).

Background reduction will be achieved thanks to an efficient and hermetic photon veto system and particle identification detectors. Decay kinematics will be used to further reduce background events, using the missing mass variable:

$$m^2_{miss} \simeq m^2_K \cdot \left(1 - \frac{|p_\pi|}{|p_K|}\right) + m^2_\pi \cdot \left(1 - \frac{|p_K|}{|p_\pi|}\right) - |p_K| \cdot |p_\pi| \cdot \theta^2_{\pi K},$$

where p_K (p_π) and m_K (m_π) are the kaon (pion) momentum and mass, respectively, and $\theta_{\pi K}$ is the angle between the two tracks.

The rate in the detectors upstream of the decay region is due to the unseparated kaon beam (mainly composed of π^+ and p: the K^+ fraction is only 6%) and amounts to about 800 MHz. Downstream detectors are subject to a total integrated rate of about 10 MHz, due to K^+ decays and halo particles. Precise timing and spatial information are required to match the upstream track with the downstream one.

2˙2. *Subdetectors description.* – After production and momentum selection, the beam first traverses the CEDAR [5], a Cherenkov differential counter for the positive identification of kaons with a time resolution of 100 ps. It will sustain an instantaneous rate of 50 MHz due to the kaon beam component. This detector is based on the existing CEDAR detectors at CERN, but features a modified mechanics and optics, plus new PhotoMultiplier Tubes (PMT) and electronics.

The momentum, direction and time of each beam particle is measured in the beam spectrometer, composed of three hybrid silicon pixel detector stations, called Gigatracker (GTK), installed in vacuum [6]. The material in each GTK station amount to less than 0.5% X_0 to minimize multiple scattering and hadronic interactions. With a pixel size of $300\,\mu\text{m} \times 300\,\mu\text{m}$ and a distance of about 10 m between consecutive stations, this system features a momentum resolution of $\sim 0.2\%$ and an angular resolution of $\sim 16\,\mu$rad in both horizontal and vertical views. The most challenging requirement on this detector is the time resolution for a single track, that should not exceed 150 ps. Prototype detectors have been tested using an infrared laser system and a high-energy hadron beam: results from the test-beam show a time resolution on single hit of ~ 175 ps using a bias of 300 V applied to the sensor.

The GTK is followed by the CHANTI, an anticoincidence detector for charged particles that surrounds the beam just before the decay region, in order to detect inelastic interactions taking place in the 3rd GTK station.

The decay region is surrounded by the Large Angle Veto (LAV) detectors [7], in order to detect photons originating from kaon decays. At the end of the decay region a large acceptance magnetic spectrometer made of 4 straw tube stations and a dipole magnet provides the missing part of the kinematic information, measuring momentum and direction of the charged decay products [8]. Each straw station is characterized by a very small mass ($\sim 0.5\%$ X_0): the material traversed by the beam is further reduced by installing the straws directly in vacuum ($\sim 10^{-6}$ mbar).

Downstream of the straw tracker, we find the RICH (Ring Imaging Cherenkov detector), that will separate π from μ in the momentum region between 15 and 35 GeV/c with a muon misidentification probability lower than 10^{-2} [9]. In addition, this detector should measure the pion track time with a resolution better than 100 ps and provide a trigger signal at the lowest level (L0). The solution adopted by NA62 is a 18 m long vessel filled with Ne at atmospheric pressure ($n - 1 = 63 \times 10^{-6}$), that means a pion threshold of about 12 GeV/c. This solution has been validated with a test-beam of a full-length prototype, and the results show on average a time resolution of ~ 70 ps, misidentification probability of $\sim 5 \times 10^{-3}$ and an angular resolution of about $60\,\mu$rad.

A Charged HODoscope (CHOD), made of scintillator material, will be used to detect possible photo-nuclear reaction in the RICH mirror plane and to back-up the RICH in the L0 trigger for charged tracks.

Further downstream, we find the photon and muon veto systems. The photon veto system should provide a π^0 rejection inefficiency at the 10^{-8} level, and hermetic coverage up to 50 mrad. It is composed of 3 sub-systems, covering different angular regions.

The LAV detector system, already introduced, covers the angular region between 8.5 and 50 mrad, and is composed by 12 stations in total (of which 11 are in vacuum and 1 downstream of the RICH). Each station is made of 5 layers of lead-glass crystals (~ 20 X_0) with attached PMT from the former OPAL electromagnetic calorimeter. The region between 1 and 8.5 mrad is covered by the Liquid kripton (LKr) electromagnetic calorimeter, while the one up to 1 mrad is instrumented with two detectors: the IRC (Intermediate Ring Calorimeter) that covers the angular region close to the inner LKr radius, and the SAC (Small Angle Calorimeter) installed behind the experimental cavern, preceded by a magnet to deflect the charged beam.

The MUon Veto system is composed of 3 stations, re-using part of the NA48 hadron calorimeter. The first two stations are made of 24 (MUV1) and 22 (MUV2) iron/scintillator layers, with alternating horizontal and vertical scintillator strips coupled to PMTs. The third station (MUV3), installed after a 80 cm thick iron wall, is made of scintillator tiles with direct coupling to two PMTs for the suppression of the Cerenkov component. The detector signal is used as a fast muon trigger in the L0 and the time resolution is better than 1 ns.

3. – Status of the experiment and conclusions

The NA62 Collaboration is building a sophisticated detector for the measurement of ultra-rare kaon decays. The design of the experimental apparatus and the R&D of the new sub-detectors are almost complete. Two important tests are taking place in 2012: a Dry Run (July) for the synchronization of different sub detectors and a test of the DAQ chain, and a Technical Run (October-December) for the commissioning of the new beam-line and the data taking with a subset of the detectors installed.

The start of the data taking is planned for 2014, with the aim of measuring about one hundred $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ events with $\sim 10\%$ background in two years.

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